TRIGGERS AND TARGETS: WHAT ARE WE AIMING FOR WITH ABALONE FISHERIES MODELS?

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ABSTRACT   A variety of quantitative measures have been applied as reference points in the management of Australian abalone fisheries. In New South Wales changes in legal-sized and mature biomass will trigger management responses, in South Australia catch rates, size composition and abundance indices provide target reference points, and in Tasmania catch rates have been used to provide triggers for management decisions. However, Victoria and Western Australia are yet to determine their reference points for abalone stock assessment. Victoria has been developing length-based fisheries models similar to those applied in NSW, and is now confronted with the necessity of converting model outputs into decision-making criteria. A Victorian fishery management plan is also under development in which reference points will be specified within a risk-based matrix of catch control rules for quota adjustment. Recent biodiversity conservation legislation, compelling fisheries management agencies in Australia to demonstrate that export fisheries managed under

their jurisdictions are ecologically sustainable, has increased the urgency to establish these reference points. The application of this legislation draws upon the 'Principles and Criteria for Sustainable Fishing' of the Marine Stewardship Council in London. We considered a range of alternative measures for reference points that may be useful as triggers and targets applied in a stochastic framework for management decisions. Although not a modelling output, one of the more consistent signals of localised depletion in the Victorian fishery relates to spatial allocation of effort at the scale of reef complexes. Reductions in annual effort applied to a particular reef system invariably precede significant decreases in abundance indices with typically large coefficients of variation and in catch rates characterised by hyperstability. Victorian abalone divers have high daily catch expectations and allocate their effort accordingly. Empirical reference points such as effort allocations provide utility for fishery management, and can be readily assimilated and adopted by industry. Consequently, we conclude that maintenance of reef-scale effort allocation and daily catch expectations should form part of a suite of fishery performance indicators and target criteria related to modelling outputs for the Victorian blacklip abalone fishery.

INTRODUCTION

The Australian Commonwealth *Environment Protection and*

Biodiversity Act 1999, effective July 2000, and proposed revisions to the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*, will mandate that Australian fisheries resources be fished in ways that can be demonstrated as ecologically sustainable. To provide guidance for assessing sustainability, the lead agency for these Acts, Environment Australia has recently released a set of three draft principles. These principles are drawn from the Marine Stewardship Council's 'Principles and Criteria for Sustainable Fishing'. Each principle is underpinned by a series of objectives and assessment criteria that will seriously challenge many conventional approaches to fisheries management, particularly with respect to ecosystem impacts.

The first principle relates to avoidance of over-fishing and promotion of stock recovery of targeted fish populations. The second principle is concerned with protecting the supporting ecosystem and the third with effective management frameworks that meet global standards for sustainable use.

Of particular interest to abalone stock assessment biologists are criteria under the first principle that there should be sound estimates of potential long-term productivity, target reference

points for levels of fishing and limit reference points beyond which stocks should not be targeted. These are criteria that stock assessment groups should be able to address with existing data and assessment techniques. Similarly, the third principle requires that each fishery have a management plan that specifies indicators of sustainability that are periodically assessed for their effectiveness. It also stipulates that reference points be determined by involving a broad representation of stakeholders. Criteria under the second principle relating to ecosystem sustainability and biodiversity are more esoteric. It will be difficult to demonstrate satisfaction of these criteria given our relatively poor understanding of ecosystem processes in abalone-dominated communities and more importantly the lack of comprehensive and spatially representative data for these communities.

Whilst other abalone-producing Australian States have management plans, Victoria has only recently embarked upon the development of a plan that will meet the future needs of its abalone fishery. As a response to Environment Australia's imminent legislation Fisheries Victoria has nominated abalone as the first fisheries resource for which they will pursue Marine Stewardship

Council accreditation. Highest priority in this regard has been given to the determination of reference points for the fishery. Unlike many fin fisheries across the globe where target and limit reference points have become well-established in fisheries management (Caddy 1998), abalone fisheries have yet to embrace a standard suite of reference points. We have already modified and applied a length-based stock-reduction model with an assumed Beverton and Holt stock – recruitment relationship to assess the Victorian fishery, in similar fashion to an approach used for the NSW fishery. There is an expectation that outputs from the model will form the basis for reference points in the management plan, as is the case in NSW. However, other States use different reference points and an examination of the efficacy of a range of alternatives is warranted. We describe and where possible evaluate some of the biological and fishery reference points currently applied in Australia in an attempt to stimulate debate about the selection of attributes to trigger management decisions and target fishery performance.

MEASURING PERFORMANCE, SETTING TARGETS AND

RESPONDING TO TRIGGERS

Terminology describing reference points can appear somewhat confusing given everyday usage and varying definitions of technical terms. Caddy (1998) uses the terms Target Reference Point (TRP) and Limit Reference Point (LRP) to refer to target values that mostly relate to recovery of over-exploited stocks and trigger values that represent thresholds for avoidance of overfishing. For the purpose of our discussion we consider reference points to be values of biological and fishery attributes that can be used to gauge performance of the fishery. In this context target reference points are desired values of selected performance indicators against which we can make assessments about the current status of an abalone stock, whereas trigger points are threshold values below which there is an unacceptable risk of adverse consequences for the fishery. Invoking these triggers should initiate management intervention before the fishery enters an undesirable state. Beyond the trigger points are limit points or values that when attained indicate

collapse of the stock is imminent. The larger the margin between trigger and limit reference points the greater the selected probability of activating the trigger without increasing the risk of stock collapse (Caddy 1998). In a stochastic framework performance indicators should specify a reference point value, the relationship between an observed value and the reference point, and the confidence probability for acceptance that the relationship is true over a specific time period. Applying reference points in a risk analysis is preferable to relying on individual deterministic values because it has the advantage of incorporating uncertainty in the decision making process.

Catch Rate

Whilst much has been written about the lack of utility in catch per unit effort (CPUE) as it is currently reported by abalone divers in most parts of the world, there are some studies that support a contrary view (Worthington et al. 1998). It is also generally acknowledged that catch rates play some role at a fine scale in

determining whether a commercial abalone diver will persist in fishing a specific population. Stock assessment teams inevitably resort to commercial catch and effort statistics and trends in CPUE when alternative data about the fishery are scant or inconsistently collected. This is a reflection of the power that comes from having large amounts of data over a time scale consistent with the history of the fishery and generally at a high temporal resolution. CPUE is used as a reference point in the South Australian abalone management plan (Zacharin 1997) and until recently was also part of the Tasmanian plan (Anonymous 1997). The South Australian plan specified that for blacklip abalone the reference point would be triggered if a change in catch rate within major fishing blocks of greater than 15 percent between years or greater than a 25 percent change over a period of five consecutive years was observed. In Tasmania two catch rate trigger points were applied (Officer 1999). One of these reference points would be triggered if annual CPUE at the State level from diver returns fell below 95% of the CPUE for the reference year (1993, 1994 or 1995) with the lowest catch rate. The other reference point would be triggered if annual CPUE from diver returns for any region or individual block

fell below 75% of the CPUE for the reference year (1993, 1994, or 1995) with the lowest catch rate for that region or block. Officer (1999) concluded that these reference points were inadequate to indicate whether or not recent catches were sustainable. The 1997/98-fishery assessment showed that at the higher spatial resolution only one statistical block was close to being triggered and that on a Statewide scale average catch rates had increased every year since 1990.

In Victoria, the abalone fishery is subdivided into three relatively large management zones each spanning several hundred kilometres of coastline (Fig. 1). However, catch and effort data are reported for area codes of tens of kilometres and reef codes that generally represent headlands or reef complexes. Average catch rates for each zone have mostly increased during the past 20 years that detailed records are available. Before we can interpret this as increased abundance we need to eliminate the possibilities that such trends are consequences of increased diver efficiency, changes in commercial divers' interpretations of effort, or access to new fishing grounds.

During the history of the fishery there have been a number

of changes in the composition of the Victorian commercial abalone diver population and divers' incentives to fish. Licence transferability was introduced during 1984 on a two for one basis followed by quotas during 1988. Between 1984 and 1988 beach prices increased three fold from about $AUD 5 – 15 per kg pushing up the price of licences. Divers who bought into the fishery frequently took out large mortgages to pay for consolidated licences, adding increased incentive to maximise the return for each unit of effort. Further changes occurred as access licence owners 'leased' their licences to contract divers, now formally recognised under the Victorian Fisheries Act (1995) as nominated divers. These divers are generally younger and fitter than the 'retiring' access licence owners and are paid about 10% of the abalone beach price. Discussions with experienced divers suggest that there has been an increase in catching efficiency during recent years. In addition we have repeatedly implored divers to record only bottom time as effort rather than time spent on the water. Compliance with this request would tend to decrease the effort reported for each unit of catch although the extent to which this has affected CPUE is unclear. More revealing

is the spatial disaggregation of effort into groups of reefs arbitrarily categorised by their long-term average CPUE. This clearly shows a trend toward effort being concentrated on those reefs that provide the highest catch rates (Fig. 2).

Discussions with divers confirm that prior to quota introduction divers would often fish low catch rate reefs. Once quotas were introduced there was no longer an incentive to fish the low catch rate reefs because quotas could be readily obtained from a smaller number of reefs where abalone were large and abundant. Indeed we have clear evidence of the hyperstability of CPUE on a reef that recently collapsed in the Eastern Zone of the Victorian fishery. The Skerries is a seal colony in a relatively remote and ostensibly pristine location. However, difficult but nonetheless available access via 70 kilometres of rough road allows abalone thieves to fish this location. Whether illegal fishing is to blame is unknown, however what is clear is that declines in pre-recruit abundance were followed by declines in the abundance of legal-size abalone at our fixed monitoring site (Fig. 3) and a concomitant decrease in effort. In contrast, CPUE increased during many of the final days of effort before licensed divers decided

harvesting abalone from this location was no longer worthwhile (Fig. 4). Big Rame Head, another important reef approximately 3.5 km to the west of The Skerries, has contributed up to 8 % of the Eastern Zone catch in previous years but is showing similar catch and effort trends to The Skerries (Fig. 5). However, declines in abundance were only recorded at the three of our five fixed monitoring sites closest to shore access and were not as substantial as declines at The Skerries.

Relative Abundance

Largely as a consequence of problems in applying conventional models to abalone fisheries (Breen 1992) and the failure of CPUE as an estimate of abundance (McShane 1992), the last decade has seen the introduction of independent dive surveys to estimate abundance of Australian abalone. It was anticipated at the outset that these surveys would provide a time series of relative abundance that would reflect changes in commercially fished abalone populations that could not be detected using catch and effort statistics (McShane 1994). The assumption was made that catch quotas would be adjusted in

response to trends in abundance, however there was no explicit adoption of such adaptive management arrangements by any of the State fisheries authorities responsible for abalone management. Indeed, abundance estimates on their own show sufficient spatial variability that the power to detect change is often low with the levels of replication allowed by available resources (Gorfine et al. 1998). Furthermore, lack of temporal resolution and infancy of these programs has made the detection of statistical trends in these data problematic. That these programs were initiated late in the development of the fishery, well after the initially rapid reduction in pre-fished biomass (Gorfine and Walker 1996), has meant that there is often little contrast in the temporal effect once residual variation has been partitioned from the data. Nonetheless, South Australia includes indices of abundance from independent dive surveys as one of the reference points in its abalone fishery management plan (Zacharin 1997). This reference point is triggered if a greater than 15 percent change is detected in the abundance of abalone above the legal minimum size, and abundance of pre-recruits between consecutive years.

Our research on independent survey methods and experience in their application for large scale monitoring during the past decade clearly demonstrates that effect sizes of 15 % are unlikely to be detected given the large coefficients of variation (CV) for abundance estimates (Hart et al. 1997). CVs from un-standardised abundance data differ substantially among size classes. Our survey data show those abalone within 10 mm above and below the legal minimum length (LML) generally have CVs less than 30%, whereas the more cryptic smaller size-classes and sparsely distributed larger classes have CVs that make the detection of changes in abundance unlikely (Table 1). Whilst we have had sufficient statistical power with our methods to detect significant changes as small as 10% on some occasions (Gorfine et al. 1998), patterns in inter-annual variability fluctuate to the extent that a substantial increase between a pair of consecutive years may often reverse during the subsequent year. Management decisions, particularly about catch quotas, made in response to unstable patterns such as these will almost certainly create more problems that they solve.

In Victoria we have now shifted our emphasis away from

direct application of abundance estimates to assess stocks status towards use of abundance to fit fisheries models to commercial catch data to describe and forecast trends in relative biomass.

Egg Production

Shepherd and Baker (1998) suggest that egg production may be an acceptable substitute for biomass to predict risks of overfishing. Their Eggs-per-recruit (EPR) analyses together with their review of EPR estimates from other studies indicates that the range 40 – 50 % is associated with sustained yields from medium to large abalone stocks and could be used as an appropriate threshold reference point. However, these values appear to have been derived from deterministic EPR models that take no account of the stochasticity in abalone growth described by Troynikov and Gorfine (1998). In addition, whilst it is reasonable to surmise that empirical evidence of sustained yield over a long period indicates a stable stock, it does not necessarily follow that the %EPR of a sustainable population can be considered as a threshold for a collapsed population with a lower %EPR (McShane 1995).

Differences of opinion exist as to the nature of stock-

recruitment relations in abalone and whether or not conserving a particular level of egg production will ensure sustainability of an abalone fishery. Even if stochastic versions of EPR models were applied, the outputs would only allow selection of size limits because these models provide no information about the effects of varying catch quotas.

Biomass

The New South Wales stock assessment team use relative biomass outputs from their length-based fishery model as performance indicators linked to two trigger points that relate to the biological objectives of the Management Plan for the NSW Abalone Share Management Fishery (Worthington et al. 1999). These reference points are specified in manner that accommodates the uncertainty associated with model outputs. The first reference point is a performance trigger that is invoked if there is more than a 50 % chance that median estimates of legal and mature relative biomass for any region, or for the entire fishery, are less than 85 % of the value for 1994. The second reference point is a forecast trigger invoked if model projections

over the ensuing five years show a greater than 50 % chance of the legal and mature relative biomass being less than 85 % of estimates for 1994. During 1998 neither trigger was invoked although at the regional scale some B/B_0 values averaged only 2 % greater than the 85% trigger point with likelihood's only 5 – 10 % less than the 50 % reference probability (Worthington et al. 1999). In the absence of target reference points implying the contrary, the premise underpinning this approach is that the state of stocks during the reference year (1994) was at an acceptable level.

In Victoria we have recently applied our version of a length-based model (unpublished). Our model differs somewhat from the NSW model because it incorporates a framework for dealing with variability in the distribution of growth within populations, and in its current form does not use effort. Like the NSW model, ours fits the model to time series of abundances of different length classes obtained from fishery independent dive surveys of commercially important populations (Fig. 1). Outputs from the Victorian model are essentially the same as those of the NSW model, however in the absence of a management plan there are no agreed reference

points against which model outputs can be assessed. In many fisheries biomass estimates are set at specific values relative to an estimated pre-fishing or virgin biomass value B_0. For instance $B_{30\%}$ has often been used as a reference point for scale fisheries particularly in the Northern Hemisphere (Quinn and Deriso 1999). However, there is no evidence that this or similar values have any relevance to invertebrate fisheries such as abalone.

What we have been able to do for the Victorian fishery is incorporate the model outputs into a risk analysis where future biomass trajectories are predicted for a given harvest strategy (proportion of current TAC) at a selected level of risk. Figure 5 shows relative biomass projections up to 25 years for different proportions of the current TAC at three levels of risk (10%, 20% and 30%). Sensitivity of these projections to three combinations of natural mortality and unaccounted catch is shown. As would be anticipated, increasing the current TAC is likely to produce a decrease in biomass. In contrast, as the level of risk selected increases the prognosis for sustaining current biomass improves. However, the projections are sensitive to levels of natural mortality and unaccounted catch. Because the model estimates its

recruitment parameters internally, high mortalities throughout the life of the fishery will tend to make it more productive whereas increased mortalities in its more recent history will tend to have the opposite effect. Issues such as when illegal fishing became a problem and whether much catch went unreported in the early years of the fishery can have profound effects of outputs from the model.

Notwithstanding the preliminary nature of these results, depletion curves from model outputs show that current biomass in the Victorian fishery is about 30% of the pre-fished biomass and 97% of the 1988 biomass (Fig. 6). Although stocks generally appear to remain in slow decline since 1988, and for future projections, most of the depletion of pre-fished biomass occurred during the first five years of the fishery, well before quota introduction.

Commercial Effort

Victorian abalone divers have high daily catch expectations and allocate their effort accordingly. Detailed observations aboard commercial abalone vessels show that these expectations are

typically about 500 kg for five hours spent at sea but may be as high as 1000 kg (Gorfine and Dixon, this publication). Where divers anticipate lower catches this almost invariably reflects the balance of unharvested quota on their last day of fishing for the year. These high catches cannot be obtained unless divers select reefs where experience has demonstrated that aggregations of abalone are numerous and dense. Divers will generally also have some perception of how well these populations recover after fishing and when they were last visited. Experienced divers will occasionally have to perform several test dives to locate good patches of abalone if recent intensive fishing has occurred and inexperienced divers may make many such dives if their local knowledge is limited.

Insights from on-board observations may lead us to develop alternative reference points based on temporal and spatial allocation of effort. The basis for this assertion is that divers respond to change in stock availability that is below the detection limits of analyses of reported catch-effort and fishery independent abundance indices. However, we must firstly account for variables that tend to confound this interpretation of effort, such as

weather, diver experience, and market requirements. One possible empirical reference point could include reef-scale effort allocation, with a trigger point set at numbers of days per reef falling below some margin of the average number of days per annum since quota introduction. Another reference point could be related to daily catch expectation with a trigger that is activated if average daily catches fall below a specified margin of an historical average.

DISCUSSION

Catch per unit effort appears to have little to offer as a reference point for abalone fisheries. Its insensitivity to changing abundance and its sensitivity to changes in the composition and behaviour of the diver population ensure that it reflects the state of the predator rather than its prey.

Reference points used widely for scale fisheries may well be inappropriate and the idea of specifying a proportion of pre-fished biomass (B_t/B_0) is presumptive of a well-defined stock recruitment relationship. McShane's (1995) review of abalone

recruitment suggests that a definitive stock recruitment relationship may forever elude abalone fisheries biologists. Shepherd and Baker's (1998) %EPR as a reference point provides no information about sustainable catch quotas. However, their conclusion that sustainability for small abalone populations may require the conservation of reproductive capacity at levels nearing 100% of the pre-fished stocks is consistent with Prince and Guzmán del Próo's (1993) stock reduction analysis of several zones in the Mexican fishery. Their analysis showed the zones to have poor productivity with little surplus yield to support sustained fishing. In another study of the Mexican fishery, Ramade et al. (1998) found that catch quotas based on conserving 75 % of the current fishable biomass were too high to prevent recruitment overfishing.

The application of current measures of relative abundance as biological reference points is unlikely to be effective for managing abalone fisheries. Incorporation of independent observations of relative abundance into the model fitting process provides more information about trends in a stock than can be gained by the use of abundance indices on their own. However, we must continue to

refine our survey methods to reduce the inherent variability in abundance data because catches must cause large changes in relative abundance for depletion models to function effectively (Walters 1999).

Relative biomass appears to be the most efficacious among performance indicators that are linked to abalone fisheries models. However, choice of reference year for the denominator of the biomass ratio will depend on some independent information about the fishery during the year selected. For the NSW fishery, 1994 was chosen because it was the year during which independent surveys of abalone abundance commenced (Worthington 1999). In Victoria a similar approach could be used by selecting 1992, when we commenced our current series of relative abundance surveys, however it may also be informative to specify 1988, the year of quota introduction, as the reference year. This is because quotas were introduced at a time when yields from the fishery had stabilised and managers and industry aspired to maintain stocks at current levels rather than to allow catches to increase and risk overfishing the resource.

Although intuitively appealing, biomass projections can be

problematic. Like all models, sensitivity to parameter values and the capacity to estimate these values empirically are issues that need to be resolved. It is almost trivially obvious that a model dependent on catch loses its reliability when a large proportion of the catch remains unaccounted. Yet this is one of the major problems facing all Australian abalone fisheries. Factoring notional unaccounted catches into a model can be counter-intuitive because, as described above, large catches tend to provide less conservative projections. Consequently, we are planning to direct future research efforts to developing robust methods for estimating illegal catches.

Our model outputs highlights the important drawback with constant harvest strategies that when biomass is declining the Total Allowable Catch represents an ever increasing proportion of the available stock (Perry et al. 1999). In the absence of timely management intervention, it is reasonable to expect declines in biomass to accelerate under quota management until some threshold is passed and the stock suddenly collapses. The modelling also shows that the introduction of quotas was not responsible for arresting declining biomass. The slowing of

biomass depletion resulted from diver attrition during the 1960s and 70s when due to low beach prices and the introduction of fees many divers decided there were insufficient incentives to continue fishing. A constant rate of fishing mortality may seem a better option than quotas and this is commonly used in scale fisheries. McAllister and Kirkwoood (1998) found that effort control management options outperformed catch control options in simulations by providing 40% more catch for the same risk of stock depletion. However this approach increases the complexity and intensity of management decisions (Perry et al. 1999)

Whilst biomass seems have the most promise for developing abalone reference points in the short-term there needs to be alternative pathways when the quantity and quality of available data inputs and parameter estimates are poor or model assumptions are substantially violated (Walters 1998). Reference points need to embrace not only model outputs but also other factors that are not modelled. For instance, until we have sufficient data to spatially disaggregate our model we require reference points suitable for addressing fine-scale changes in stocks at the scale of bays and headlands. Reference points also

need to be sufficiently diverse to provide empirical alternatives as reality checks on model.

The use of effort as an indicator of stock status may be of benefit under such circumstances, however spatial and temporal shifts in effort must be treated cautiously so that reasons unrelated to the state of the resource can be eliminated. It may be possible however to use average values of daily catch expectation and aggregate days of effort per reef as performance triggers that initiate management action when some pre-determined threshold is passed. Indeed, Walters (1998) makes the point that there is potential for novel indicators of overexploitation to be developed based on the detailed information available in catch statistics. We believe the spatial resolution in catch and effort data has yet to be used to its full potential in managing abalone fisheries.

The adoption of multi-species approaches, focussing on so-called keystone species in addition to the target species is a noble and possible essential goal. However, our current survey techniques are already costly and consequently can only accommodate abundance estimates of relatively few organisms. It

is unclear how we can attempt to model abalone ecosystems until we have a better understanding of density dependence, inter-specific competition and trophic interactions.

Whatever reference points are adopted for the Victorian fishery for incorporation into its management plan, involvement of stakeholders will be a critical part of the reference point selection process to ensure that triggers and targets are meaningful and of practical value. An inclusive process of involving stakeholders in the pre-negotiation of reference points is also required to ensure consensus about management prescriptions (Caddy 1998). Without ownership of the management process by stakeholders compliance and reporting problems will prevail under adverse circumstances. Access licence owners will be wary of providing any information that that they perceive may decrease the value of their entitlement both in direct monetary terms and as security to obtain credit finance. Contract divers (and processors) make their money on volume and their focus is on the short rather than the long-term situation hence a rush on declining stocks to get the most out whilst still able would be inevitable.

The establishment of a suite of empirical and model-based

reference points within an agreed decision-making framework in a management plan underpinned by comprehensive catch and effort reporting and broad-scale fishery monitoring should ensure that the Victorian abalone fishery satisfies the ecological sustainability requirements of Commonwealth legislation. It is hope that this will provide the Victorian abalone industry with a competitive edge in marketing its products as "environmentally friendly".

ACKNOWLEDGMENTS

LITERATURE CITED

Anonymous. 1997. Draft abalone management plan and policy document. Department of Primary Industries and Fisheries, Hobart, Tasmania.

Breen, P.A. 1992. A review of models used for stock assessment in abalone fisheries. In S.A. Shepherd, M. Tegner & S.A. Guzmán del Próo (Eds.). Abalone of the world: biology, fisheries and culture. pp. 318 – 338. Blackwell, London.

Caddy, J. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. *FAO Fish. Tech. Paper* No. 379. Rome, FAO 30pp.

Gorfine, H.K. & C.D. Dixon. 2000. A behavioural rather than resource focussed approach may be needed to ensure sustainability of quota managed abalone fisheries. *J. Shellfish. Res*. This publication.

Gorfine, H.K., D.A. Forbes & A.S. Gason. 1998. A comparison of

two underwater census methods for estimating the abundance of the commercially important blacklip abalone, *Haliotis rubra*. *Fish. Bull.* 96, 438 – 450.

Gorfine, H.G. & T.I. Walker. (Eds.) 1996. Abalone – 1996. Compiled by the Abalone Stock Assessment Group. Fisheries Victoria Assessment Report No. 9. Fisheries Victoria, East Melbourne, 54 pp.

Hart, A.M. H.K. Gorfine & M.C. Callan. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) I. An analysis of diver-survey methods for large-scale monitoring. *Fish. Res.* 29: 159 – 169.

McShane, P.E. 1992. Exploitation models and catch statistics of the Victorian fishery for abalone *Haliotis rubra*. *Fish. Bull.*, 90: 139 – 146.

McShane, P.E. 1994. Estimating the abundance of abalone (*Haliotis* spp.) stocks: examples from Victoria and southern New Zealand.

Fish. Res., 19: 379 – 394.

McShane, P.E. 1995. Recruitment variation in abalone: its importance to fisheries management. *Mar. Freshwater Res*., 46: 555 – 70.

McAllister, M.K. & G.P. Kirkwood. 1998. Using Bayesian decision analysis to help achieve a precautionary approach for managing developing fisheries. *Can. J. Fish. Aquat. Sci.* 55: 2642 – 2661.

Officer, R.A. 1999. Fishery Assessment Report: Tasmanian abalone fishery 1997/98. Tasmanian Aquaculture & Fisheries Institute, University of Tasmania, 68 pp.

Perry, R.I., C.J. Walters, & J.A. Boutillier. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. *Rev. Fish Biol. & Fisheries*, 9: 125 – 150.

Prince, J.D. & S.A. Guzmán del Próo. 1993. A stock reduction analysis of the Mexican abalone (Haliotid) fishery. *Fish. Res.* 16: 25 – 49.

Quinn, T.J. & R.B. Deriso. 1999. Quantitative fish dynamics. Oxford UP, New York, 542 pp.

Ramade-Villanueva, M.R., D.B. Lluch-Cota, S.E. Lluch-Cota, S. Hernandez-Vazquez, A. Espinoza-Montes & A. Vega-Velazquez. 1998. An evaluation of the annual quota mechanism as a management tool in the Mexican abalone fishery. *J. Shellfish Res*., 17: 847 – 851.

Shepherd, S.A. & J.L. Baker. 1998. Biological reference points in an *abalone (Haliotis laevigata)* fishery. *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. G.S. Jamieson and A. Campbell (eds.). *Can. Spec. Publ. Fish. Aquat. Sci.* 125: 235 – 245.

Troynikov, V.S. & H.K. Gorfine. 1998. Alternative approach for establishing legal minimum lengths for abalone based on stochastic growth models for length increment data. *J. Shellfish. Res.* 17: 827 – 831.

Walters, C. 1998. Evaluation of quota management policies for developing fisheries. *Can. J. Fish. Aquat. Sci.* 55: 2691 – 2705.

Worthington, D.G., N.L Andrew & N. Bentley. 1998. Improved indices of catch rate in the fishery for blacklip abalone, *Haliotis rubra*, in NSW, Australia. *Fish. Res.* 32: 223 – 231.

Worthington, D.G., C. Blount, R.C. Chick,. & P.T. Gibson. 1999. An assessment of the NSW fishery in 1998. Fishery Resource Assessment Series No. 6, NSW Fisheries Research Institute, Cronulla, 55 pp.

Zacharin, W. (Ed.). 1997. Management plan for the South Australian abalone fishery. Primary Industries South Australia,

Adelaide & South Australian Research and Development Institute.

TABLES

Table 1.

Ranges of coefficients of variation, during 1992 – 98, for relative abundance estimates of five size-classes of blacklip abalone surveyed in the three management zones of the Victorian fishery.

Size-class	Central Zone*	Eastern Zone	Western Zone
80 – 99 mm	1.10 – 2.09	1.09 – 2.28	1.55 – 4.69
100 – 109 mm	0.43 – 0.71	0.50 – 0.74	0.48 – 0.80
110 – 119 mm	0.14 – 0.23	0.31 – 0.52	0.17 – 0.34
120 – 129 mm	0.18 – 0.22	0.18 – 0.27	0.09 – 0.12
130 + mm	0.82 – 0.89	0.31 – 0.58	0.46 – 0.84

* Size classes are 10 mm less in all instance because LML = 110 mm in most of this zone, compared with 120 mm elsewhere.LIST OF FIGURE CAPTIONS

Figure 1. MAP Locations of blacklip abalone (*H. rubra* Leach)

collection sites along the coast of Victoria, Australia.

Figure 2. Annual effort (days) from 1978 – 98 for reefs from the Central Zone of the Victorian abalone fishery with high (> 61 kg/h), medium (55 – 61 kg/h) and low (< 55 kg/h) average catch per unit effort (CPUE).

Figure 3. Relative abundance of legal-size and pre-recruit abalone from 1992 – 99 at The Skerries in the Eastern Zone of the Victorian abalone fishery.

Figure 4. Catch per unit effort (mean $kgh^{-1} \pm SD$) and annual effort (days) from 1978 – 98 at The Skerries in the Eastern Zone of the Victorian abalone fishery.

Figure 5. Annual catch (tonnes), catch per unit effort (kgh^{-1}) and effort (days) from 1978 – 98 at Big Rame Head in the Eastern Zone of the Victorian abalone fishery.

Figure 6. Relative biomass projections for Eastern Zone for

different harvest strategies at three levels of risk showing

sensitivity to three combinations of natural mortality and

unaccounted catch.

[B_T is biomass at projected time period T (years) (B_0 is initial

   biomass),

B_T/B_0 is expressed as a proportion (0.1, 0.2, 0.3, 0.4, 0.5 and

0.6),

constant harvest strategy is expressed as percentage of current

TAC (80, 90, 100, 110 and 120%),

risk is expressed as a percentage of B_0 (10%, 20% and 30%),

and

projected time period is T years beyond 1998 (T=0, 5, 15 and 25

years).

U is unaccounted catch as %TAC, M is rate of natural mortality]

Figure 7. Biomass depletion (with 95% probability interval) for

legal-size abalone (projections with current TAC and assumed

values of unaccounted catch) in the (a) Western Zone, (b) Central

Zone and (c) Eastern Zone of the Victorian abalone fishery.